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MODELLING AND SIMULATION OF BLDC MOTOR FOR INDUSTRIAL APPLICATIONS

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ABSTRACT

Permanent magnet synchronous motor has attracted by various applications such as commercial, domestic and industrial due to low cost and its several advantages. The main purpose of this paper is to describe Brushless DC (BLDC) motor drive for industrial applications. Conventional six switch inverter drive of PMBLDC motor is replaced by four switch PMBLDC motor drive for industrial applications to make the system simple and less expensive. A comparative study of both, six switch drive circuit and four switch drive circuit for PMBLDC motor used in industrial application has been discussed. Performance and result is explained in terms of back EMF, torque-speed characteristics of PMBLDC motor for both drives. The simulation results are carried out in MATLAB-Simulink software to compare the results.

KEYWORDS: Four Switch Drive, Hysteresisi Current Controller, Permanent Magnet BLDC Motor & Six Switc Drive

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Original Article

INTRODUCTION

Permanent magnet brushless DC motors (PMBLDC) are widely used in various applications due to its advantages like simple structure, low cost motor, better efficiency, high reliability, compact motor, low maintenance cost and high power density. PMBLDC motors are broadly used in servo and low-power drive systems. They are capable of producing speed-torque characteristics according to requirements of PMBLDC motors and drive circuits are the main considerations for cost-effective system. PMBLDC motor without hall sensors and drives with simple structure and with easy control can reduce the cost of the PMBLDC drive system for specific application. The cost of the drive for motor is reduced by two approaches, first is topological and another is controlling approach. In a first approach numbers of switches used for drive components are reduced for low cost system and in second approach different control techniques or algorithms are used for minimizing the cost of the drive system of PMBLDC motor. Therefore, due to improvements, and design revolution in power electronics can lead to utilization of PMBLDC motor in different household, commercial and industrial applications. Features like good dynamic ability for speed torque response, low losses, high torque-weight ratio and silent operation makes PMBLDC motor more efficient. This paper relates the working of four switch configuration and six switch configuration of PMBLDC motor drive for industrial applications. Also comparison has been made between both the configurations in terms of speed-torque characteristics of the same rating PMBLDC motor according to load requirement. Gate signals with current control method are used for switching the inverter for desired speed-torque value of the motor. Detailed theoretical approach of four-switch configuration of PMBLDC motor is well explained in this paper. Comparative performance and result analysis between both six switch and four switch configurations is carried out in MATLAB Simulink software. PMBLDC motor drive [1, 2,

3, 4]

Permanent Magnet BLDC Motor

The main advantage of PMBLDC motor is that the torque generated by the motor is constant. There are two types of the permanent magnet motor depending on back EMF generated by the motor. Permanent magnet motor with sinusoidal back EMF called as permanent magnet synchronous motor (PMSM) and permanent magnet motor with trapezoidal back EMF called as permanent magnet brushless DC (PMBLDC) motor. Both the motors are same, according to equivalent circuit diagrams. PMBLDC motor is similar to brushed DC motor, but in PMBLDC motors, mechanical commutator is absent hence called as brushless DC motors. For commutation process, PMBLDC motor uses an electronic inverter that is the commutation action of motor is done by controlling the switching of inverter or also called as drive circuit of PMBLDC motor. There are various drive circuits or different inverter configurations are used for controlling the commutation process of PMBLDC motor. Depending upon the requirements of the application, drive circuit is decided for the PMBLDC motor to produce desired speed-torque characteristics.

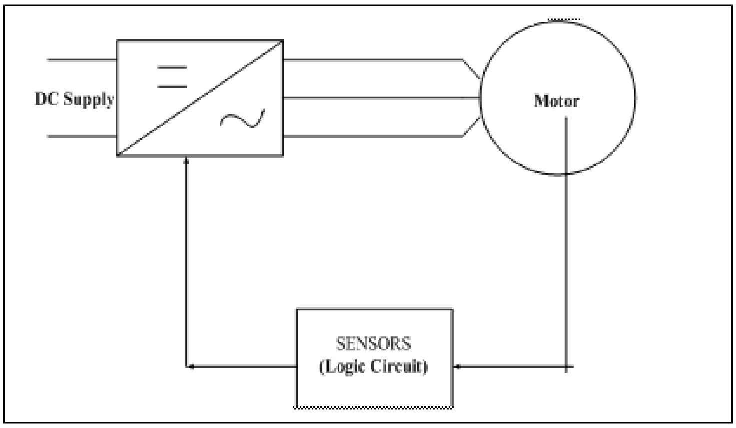


Figure 1: Basic Block Diagram of PMBLDC Motor

DC supply is given to electronic inverter and by switching of inverter, commutation of PMBLDC motor is done for obtaining precise torque. Position sensors also called as hall sensors which are used to sense the position of the rotor. By sensing the position of rotor, hall sensors produce hall signals and send it to logic circuit in which decoder is placed to produce gate signals for the inverter of PMBLDC motor drive circuit. According to hall signals gate triggering of electronic inverter is done. Small rating PMBLDC motor for low power applications does not need position sensors (hall sensors) due to small size and low housing of motor.

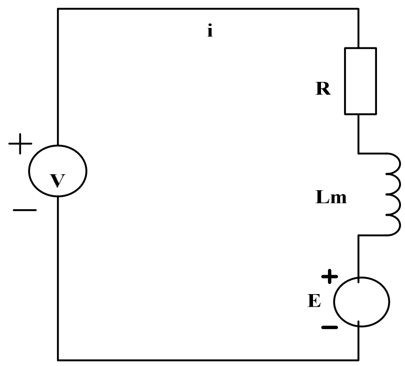


Figure 2: Equivalent Circuits for PMDC Motors

Figure 2 shows the equivalent circuit of PMBLDC (or PMSM motor) and Equation (1) shows the back EMF equation of PMBLDC motor.

$$V = E + Ri + Ldi / dt \tag{1}$$

Where V, E, R, i, L are the voltage, back EMF, armature resistance, armature current and inductance of motor, respectively. This is obtained by simply applying KVL to an equivalent circuit of PMBLDC motor. For electronic inverter, different types of switches are used like MOSFET, IGBT and IGCT for making the system more reliable and more effective. Current shape required for PMBLDC motor is a quasi-square type waveform and trapezoidal shape waveform of 120° conducting period and 60° non conducting period and to get these waveforms for PMBLDC motors, different types of PWM strategies can be used [6].

PMBLDC Motor for Magnetic Stirrer

PMBLDC motor can be used for various industrial applications. In this paper, more focus is given to the magnetic stirrer application. It is the industrial application used in a pharmaceutical industry, which is used for mixing the two or chemicals (liquids). Figure 3, shows the image for magnetic stirrer.

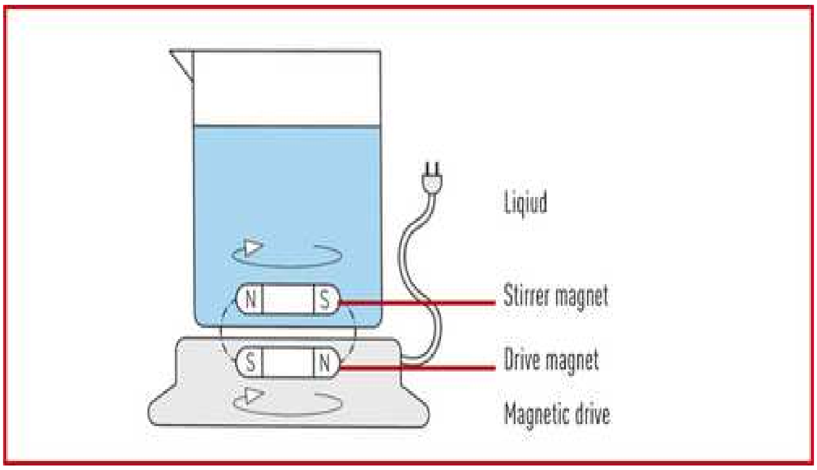


Figure 3: Magneticstirrer

In most of the stirrers DC motors are used conventionally, but these motors can be replaced by PMBLDC motor, its advantages as discussed for low cost of the stirrers. The requirement of this application is to produce constant speed at rated torque. It requires a small rating PMBLDC motor. Therefore, it does not need hall sensors, due to small rating of the motor. 6W, 10W, 18W, 24W, 60W, 96W are some of the small rating motors used for this industrial application. In this paper, 67 W motor is selected and according to load requirements, design of this motor is done using JMAG software. Figure 4, shows the motor characteristics of the selected motor used for the magnetic stirrer application.

$$T = kD^2L \tag{2}$$

Where,

T – Torque of motor, K – Motor Constant,

D – rotor diameter, L – axial rotor length.

$$K_t = \frac{T}{I} \tag{3}$$

Where,

K_t- Torque constant, T – Torque,

I – Current of motor.

$$K_b = 0.985 \times K_t \tag{4}$$

Where,

K_b – back emf constant.

$$P.F = \frac{Cos^{-1}(P_{out})}{VI} \tag{5}$$

Where,

P.F. – power factor, P_{out} – power output,

V and I – voltage and current, respectively.

$$Ironlosses = I^2{}_L R \tag{6}$$

Where,

I_L – loadcurrent, R – phase resistance.

SIX SWITCH PMBLDC MOTOR DRIVE

The conventional PMBLDC motor consists of six switch inverter for the commutation process. Six step commutations take place in this six switch PMBLDC motor drive. Figure 4, shows the six switch inverter drive for PMBLDC motor. The conduction period for every phase is 120 ° by electrical position and non-conduction periodis of 60 degree duration. Maximum torque was reached, when both the stator and rotor field are perpendicular.

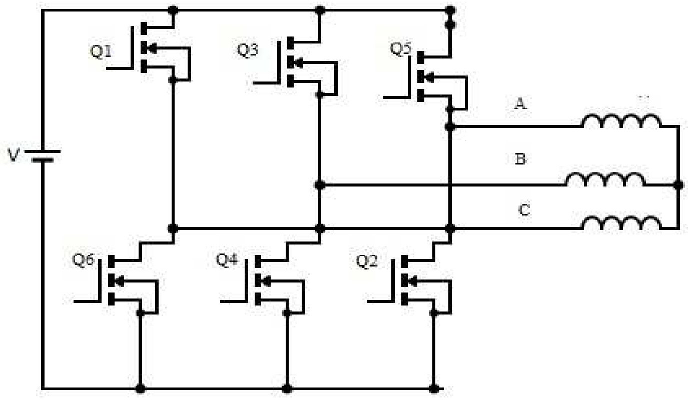


Figure 4: Six Switch PMBLDC Motor Drive

The switching sequence for the operation of PMBLDC motor is given in table 1. According to which, switching of six switch inverter has been done [6].

Table I: Switching Sequence for Six Switch Inverter PMBLDC Motor Drive

Switching Interval	Switched closed		Phase Current		
			A	B	C
0°-60°	Q1	Q4	+	-	OFF
60°-120°	Q1	Q6	+	OFF	-
120°-180°	Q3	Q6	OFF	+	-
180°-240°	Q3	Q2	-	+	OFF
240°-300°	Q5	Q2	-	OFF	+
300°-360°	Q5	Q4	OFF	-	+

FOUR SWITCH PMBLDC MOTOR DRIVE

Four switch BLDC drives need only two phases for the operation of the drive instead of using six switches in the drive. It is applicable, due to characteristics of PMBLDC motor i.e., only two phases are active at a time and remaining phase is kept, as a silent phase. This adds to the reduction in cost and increase the simplicity of the drive. It is quite difficult to generate 120° conducting and 60° non-conducting waveforms. Instead of conventional PWM techniques, it can be controlled by hysteres is current control method. In this method, two phase currents are to be directly controlled by the means of hysteres is current control method and hence, this is called as 'Directly controlled PWM method [1, 7,8].

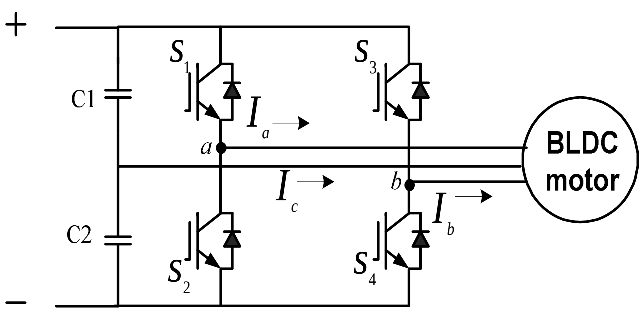


Figure 5: Four Switch PMBLDC Motor Drive

Under balanced condition, three phases current satisfies the following condition.

$$I_a + I_b + I_c = 0 \tag{7}$$

This equation (2), can be written as,

$$I_c = -(I_a + I_b) \tag{8}$$

As in induction motor drive circuit, atevery instant, all three phase currents regularly pass through the load i.e.,

$$I_a \neq 0, I_b \neq 0, I_c \neq 0 \tag{9}$$

But in PMBLDC motor drive, it is not applicable according to its characteristics.

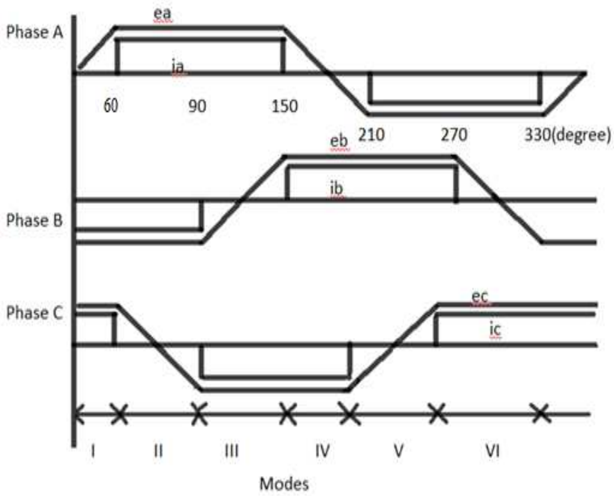


Figure 6: EMF (Back) and Profiles of Currents for Four Switches Drive [13]

Table 2: Current Equations for Four Switch PMBLDC Motor

Mode 1	$I_B + I_C = 0$, $I_A = 0$
Mode 2	$I_A + I_B = 0$, $I_C = 0$
Mode 3	$I_A + I_C = 0$, $I_B = 0$
Mode 4	$I_B + I_C = 0$, $I_A = 0$
Mode 5	$I_A + I_B = 0$, $I_C = 0$
Mode 6	$I_A + I_C = 0$, $I_B = 0$

Figure 6, shows ideal waveforms for the back EMF and current profiles for PMBLDC motor and table 2, shows the current equations for PMBLDC motor. Only two phases are active and remaining is floating at every modes of operation. In this, only two phases are controllable i.e, phase a and phase b. Phase c is always active, because it is directly connected to the midpoint of capacitances and hence, it is uncontrollable but by controlling any two phases, PMBLDC motor operation can be controlled. Hence, from the characteristics of PMBLDC motor, Table 1 implies that only two phases are need to control As per Table 1, one can achieve switching sequences by using four switch drive configuration of PMBLDC motor. Table 3 shows the switching sequences which are developed from the current equations present in Table 2 [8, 9, 10].

Table 3: Switching Sequence of Four Switch PMBLDC Drive

Modes	Active Phases	Quite Phases	Switching Device
Mode-1	Phase B, phase C	Phase A	S_4
Mode-2	Phase A, phase B	Phase C	S_1, S_4
Mode-3	Phase A, phase C	Phase B	S_1
Mode-4	Phase B, phase C	Phase A	S_3
Mode-5	Phase A, phase B	Phase C	S_2,S_3
Mode-6	Phase A, phase C	Phase A	S_2

Based on the switching sequence, the actual current regulation was done by the hysteres is current controller, which helps to produce qausi-square current waveform swith, in the reference current band limit. The main objective of current regulation is the shape of the quasi square waveform of current and trape zoidal waveform of back EMF, with acceptable switching band limit for the controller. If the phases A and B are considered as independent current sources, then the distorted back EMF of phase C can be blocked. Hence by controlling the two phases A and B, phase C current can

be controlled [11, 12, 13].

SYSTEM DESCRIPTION AND SIMULATION RESULTS

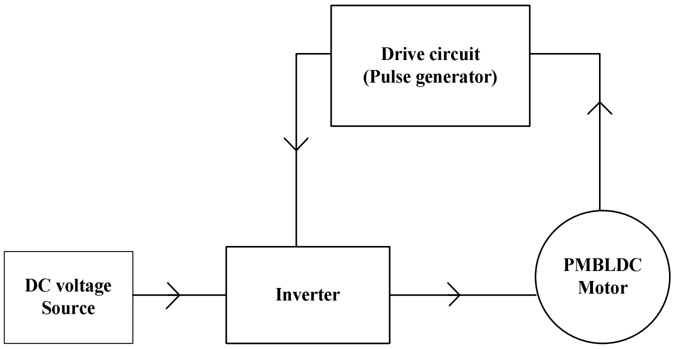


Figure 7: Basic Block Diagram of System

Figure 7 shows the basic block diagram for both systems i.e, six switch PMBLDC motor drive and four switch PMBLDC motor drive, respectively. Table 4 shows the PMBLDC motor specifications, to examine the performance of both the systems for the same rating motor. This can be used in pharmaceutical company, as a magnetic stirrer. Hall sensors can be avoided where, the rotor is closed in the housing of motor, due to small size motor. The Main requirement of this application is to get required speed at desired torque. By sensing the current from stator side of motor and controlling it to limited band with the help of hysteresis current controller, to get quasi-square current waveforms. For this, reference current is given to pulse generator, for switches, for controlling the switching of the inverter of motor [14, 15, 16]. Switching of inverter is done with the help of pulse generator and hysteresis current controller, for getting speed as required for specific application.

For hysteres is current controller, reference current is given by,

$$I_{reference} = \frac{T_{reference}}{K_b} \tag{10}$$

Where,

T_{ref} - Torque reference, K_b - Back emf constant.

Figure 8 and Figure 9, shows the Simulink model for both i.e, six switch and four switch PMBLDC motor drive, respectively.

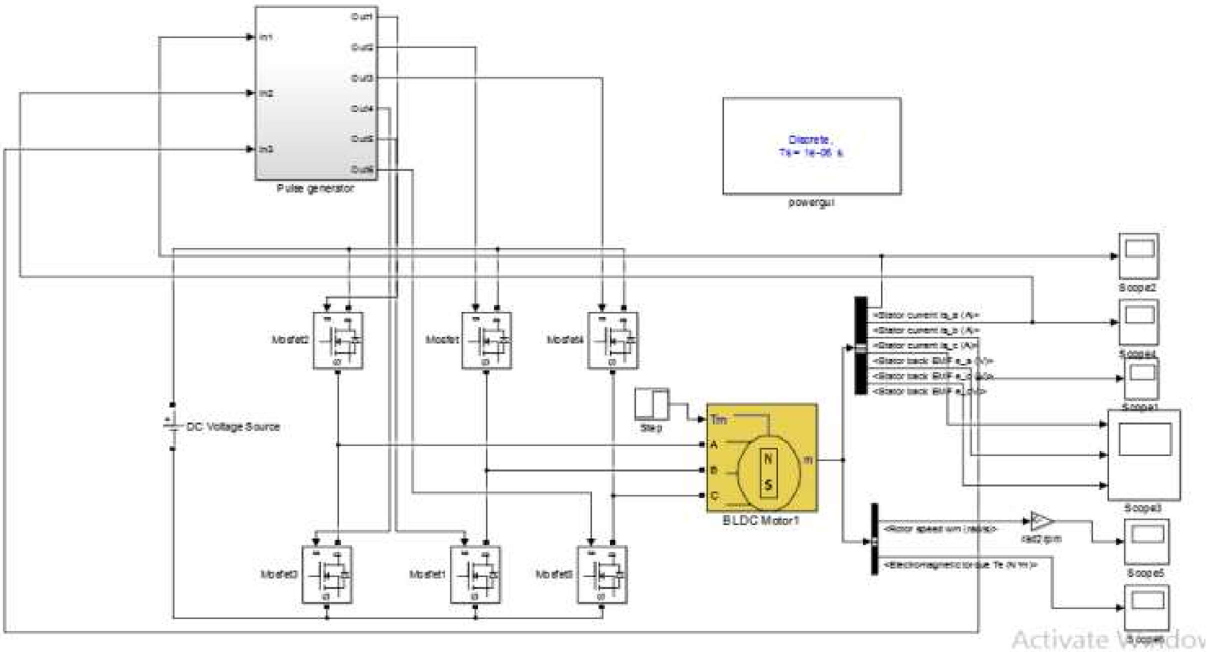


Figure 8: MATLAB- Simulink Model for Six Switch PMBLDC Drive

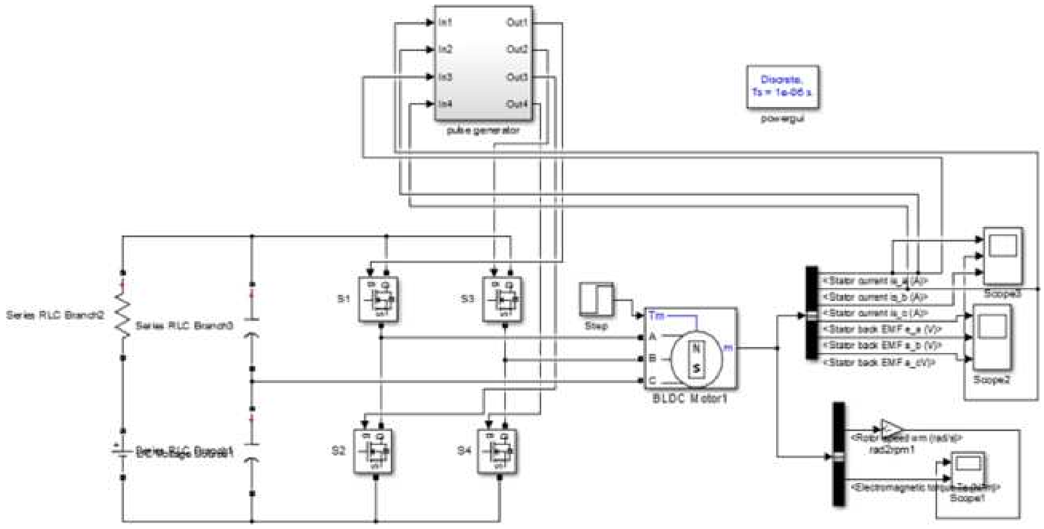
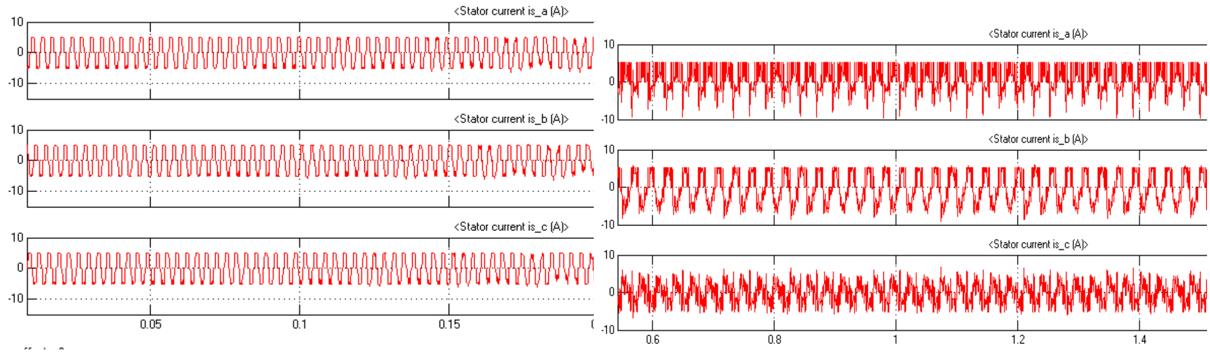


Figure 9: MATLAB- Simulink Model for Four Switch PMBLDC Motor Drive

The main purpose of this paper is to compare the drive systems and perfomance, between the six switch and four switch drives for the same rating PMBLDC motor, for specific requirement of same application in industry. In both the simulink models, pulse genearator and hysteresis current controller are used for gate signals of inverter for commutation. Switching is given, according to their respective switching sequences.

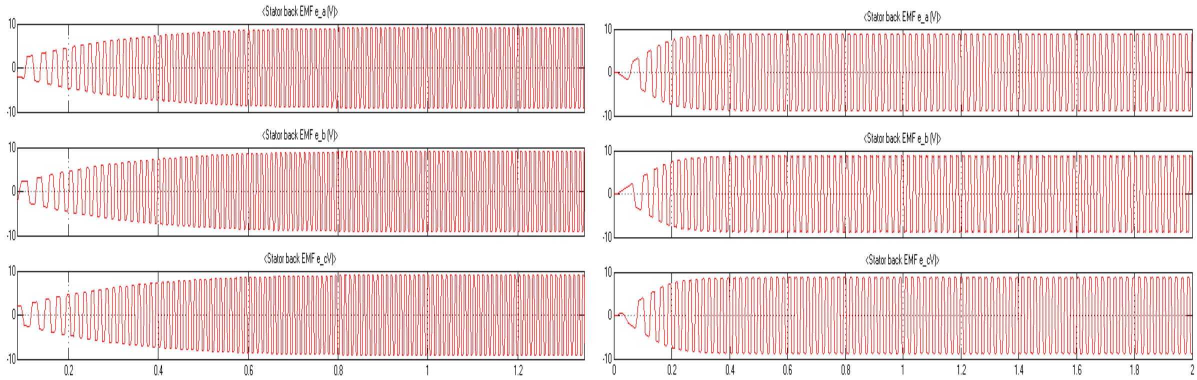
TableIV: Motor Parameters for Selected Application

P	67 W	Z_p	4 pole
T	0.6 N-m	K_t	0.118205 N-m/A
R	0.255574 Ω	I	4.5 A
L_s	0.2344 mH	V_{DC}	24 V
K_t	0.118205 N-m/A	N_{rated}	1500 rpm



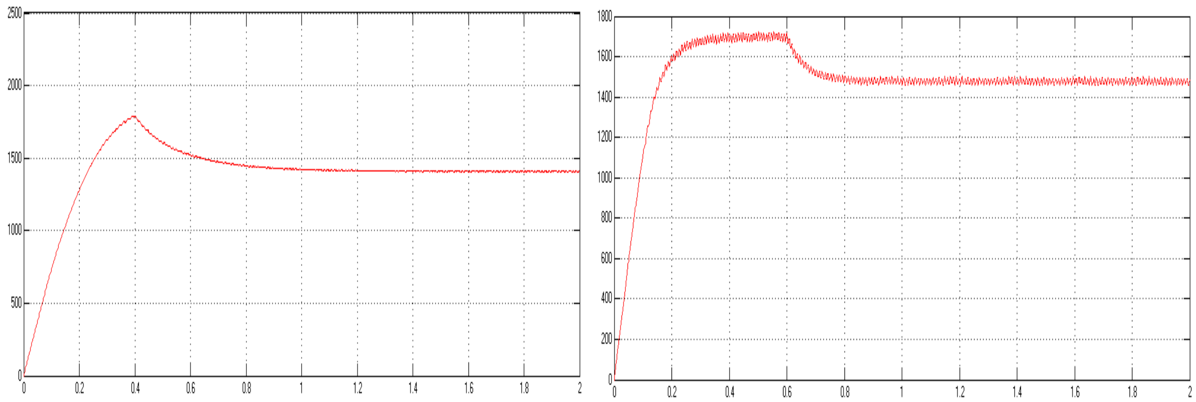
(a) (b)

Figure 10: Phase Current Waveforms for Six Switch (A)and Four Switch (B) PMBLDC Motor Drive



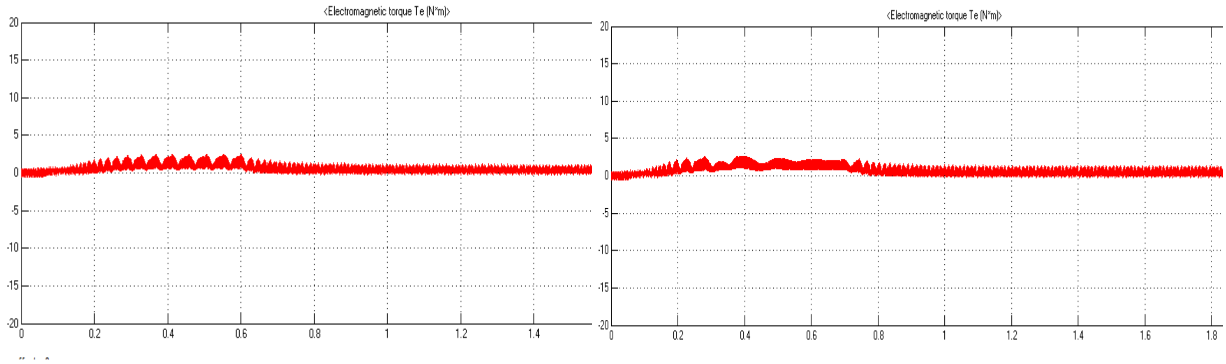
(a) (b)

Figure 11: Back Emf Waveforms for Six Switch (A) And Four Switch (B)PMBLDC Motor Drive



(a) (b)

Figure 12: Speed Response for Six Switch (A) and Four Switch (B) PMBLDC Motor Drive



(a) (b)

Figure 13: Torque Response for Six Switch (A) And Four Switch (B) PMBLDC Motor Drive

DISCUSSIONS

Introduction to permanent magnet BLDC has been studied. Six switch and four switch converter topologies required to control PMBLDC motor has been studied, with their various advantages and limitations. The six switch converter topology contains more number of switches and requires complex switching circuit and controller. It has one more leg than four switch converter, which contributes to more switching losses and affects system efficiency. In four switch converters, number of switches gets reduced by using one of the phases connected to common point of two split capacitors. All three phases can be controlled by using only four switches, which reduces the complexity of the converter circuit and makes its control simple. The output torque and the speed was found to be equal, for both the topologies and machine performance remains nearly same. The efficiency of four switch converter is slightly higher, because of lower switching losses and cost of the four switch PMBLDC motor drive gets reduced. This shows that, the PMBLDC motor can be used in various industrial applications, by using four switch inverter drives, with satisfactory performance. Low rating of motors were preferred to senseless control methods, due to small size. Small size motor used in magnetic stirrer does not required precise control of motor. Therefore, it is directly controlled through inverter for commutation, by using hysteresis current control to get required quasi-square current waveforms and to get only required output of motor, in terms of required speed and torque.

CONCLUSIONS

In this paper modelling, simulation of motor is carried out for an industrial application of magnetic stirrer. This model can be used for other small rating applications. The simulation in MATLAB Simulink software has been performed with the six switches and four switch convertert opology, which shows nearly same speed and torque output for the same rating of motor. The output waveforms are compared to parameters obtained from simulation motor, by JMAG software of same rating motor and also compared to the theoretical calculation parameters, which are nearly same. The switching of four switch PMBLDC inverter is quietly difficult, because one phase is directly connected to mid-point of two DC-link capacitors. Slight mismatch in switching may affect the performance of motor. The torque distortion, present in motor output can minimize by implementation of proper control method and proper switching. Both models are simulated to get required speed-torque load, characteristics according to load. For small rating motor and applications like magnetic stirrer, which is having only constant speed requirement, four switch drive is better in terms of cost, switching loss due to less number of switches and simple in construction, than six switch drive for PMBLDC motor.

REFERENCES

1. *Byoung-Kuk Lee,Tae-Hyung Kim,"On the Feasibility of Four-Switch Three-Phase BLDC Motor Drives for Low Cost Commercial Applications : Topology and Control" IEEE Transactions on Power Electronics, vol.18, No.1,January 2003.*
2. *V.Krishnaveni, K.Kiruthika, S.Sathish Kumar," Design and Implementation of Low Cost Four Switch Inverter for BLDC Motor Drive with Active Power Factor Correction", ICGCCEE, Iternational conference, oct.2014*
3. *S. Kanjhani, M. Gupta, H. Singh, " Review of different control topologies for the permanent magnet brushless DC motor drives," IJAERS, vol. 2, Issue 1, Oct.-Dec., 2012.*
4. *Paul Acarnley and John Watson, "Review of Position Sensorless Operation of Brushless Permanent-Magnet Machines," IEEE Transaction, vol. 53, no.2, pp 0278-0046, April 2006.*
5. *Chang-liangXia, " Permanent Magnet Brushless DC motor drives and control," first edition, Wiley& Sons publications, pp-30-36,2012.*
6. *R. Krishnan, " Permanent Magnet Synchronous and Brushless DC Motor Drives," CRC Press publications, pp- 513, 2010.*
7. *J. E. Muralidhar, Dr. Varanasi, "Anaysis of four switch and six switch converterfed BLDC motorwithfixed and variable speeds".IJESR, vol. 4, Issue 6, June 2014.*
8. *P. Chahande, S. Muley, S. Suke, "Perfomance & Analysis of Four Switch Three Phase Inverter Control for BLDC Motor Using MATLAB- A Review", Discovery Publications, Volume 19, Number 58, pp. 64-68, May 2014.*
9. *V. Krishnakumar, S. Jeevanandhan, "Four-Switch Three Phase Inverter Control of BLDC Motor," IEEE, ICEES, pp- 816, 2011.*
10. *K.-W. Lee, D.-K. Kim, B.-T. Kim, and B.-I. Kwon, "A novel starting method of the surface permanent-magnet BLDC motors without position sensor for reciprocating compressor," IEEE Trans. Ind. Appl., vol. 44, no. 1, pp. 85–92, Jan./Feb. 2008.*
11. *S.Sathish Kumar,Dr. R.Meenakumari.R,"Embedded System Based Control Of BLDC Motor Drive for Commercial and Industrial Applications",International Journal of Mechanical and Mechotronics Engineering IJMME-IJENS Vol:14 No:04,August 2014*
12. *D.-K. Kim, K.-W. Lee, and B.-I. Kwon, "Commutation torque ripple reduction in a position sensorless brushless DC motor drive,"IEEE Trans. Power Electron., vol. 21, no. 6, pp. 1762–1768, Nov. 2006.*
13. *Geethu James, Prof. K Radhakrishnan, Mrs.Jaya B,"Four switch BLDC motor drive",IJAREEIE,vol.2,special issue 1, December 2013.*
14. *Rahul khopkar, S.M. Madani," A low cost BLDC motor drive using buck-boost converter for residential and commercial applications", 0-7803-7817-2/03/IEEE,2003,*
15. *Kun xia,Liaon shen,Bin dong," Research of Four-Switch Three-Phase BLDC Motor Control Scheme Based on Quasi Z-Source Converter", 18 th ICEMS,oct.2015.*
16. *M .S. Aspalli,Farhat Mubeen Munshi,Savitri.L.Medegar," Speed control of BLDC Motor with Four Switch Three Phase Inverter using Digital Signal Controller", IEEE, 978-1-4799-8371-1/15/2015*